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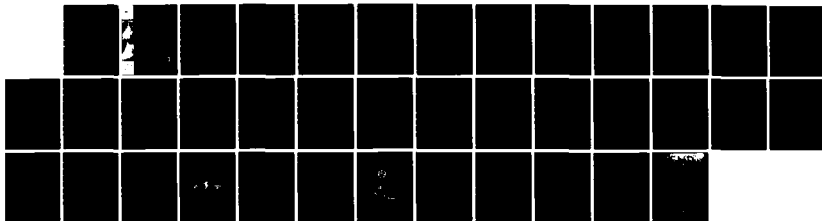
TECHNIQUES TO REDUCE THE SEDIMENT RESUSPENSION CAUSED  
BY DREDGING(U) ARMY ENGINEER WATERWAYS EXPERIMENT  
STATION VICKSBURG MS ENVIRONMENTAL LAB G L RAYMOND  
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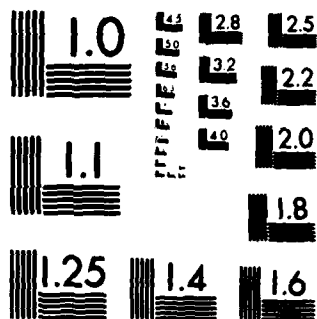
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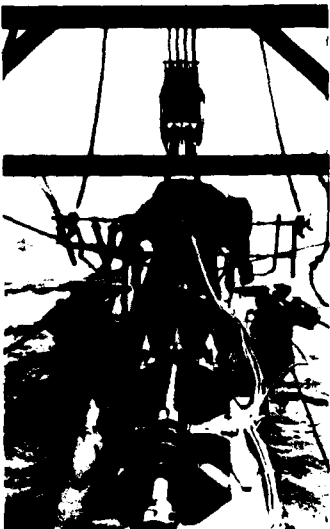
# TECHNIQUES TO REDUCE THE SEDIMENT RESUSPENSION CAUSED BY DREDGING

by

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September 1984  
Final Report

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper HL-84-3	2. GOVT ACCESSION NO. AD-A146 898	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) TECHNIQUES TO REDUCE THE SEDIMENT RESUSPENSION CAUSED BY DREDGING		5. TYPE OF REPORT & PERIOD COVERED Final report
7. AUTHOR(s) Gene L. Raymond		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Engineer Waterways Experiment Station Environmental Laboratory PO Box 631, Vicksburg, Mississippi 39180-0631		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS DEPARTMENT OF THE ARMY US Army Corps of Engineers Washington, DC 20314-1000		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE September 1984
		13. NUMBER OF PAGES 33
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES  Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Dredging--Technique (LC) Sediments, Suspended (LC) Dredges (LC)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) As part of a larger effort under the Improvement of Operation and Maintenance Techniques Program to develop a method to predict the extent of sediment resuspension and contaminant release when dredging in contaminated sediments, the U. S. Army Engineer Waterways Experiment Station's Water Resources Engineering Group is conducting field studies, to evaluate new and existing dredging methods. These studies consist of efforts to determine the level of sediment resuspended by a given dredge type in a given sediment. Whenever (Continued) 4		

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20. ABSTRACT (Continued).

possible, the studies are conducted such that different dredges operate under the same conditions or even in the same locations. The studies also evaluate the effects of various operational parameters on the resuspension of sediments. This paper presents the results of the first 2 years of study and includes data from both field studies and extensive literature review.

Different dredge types produce different amounts of suspended sediment in different parts of the water column. Resuspensions caused by cutterhead and hopper dredges tend to remain in the lower water column, while bucket dredges increase resuspensions throughout the water columns. The amount of resuspension caused by a given dredge type also depends on the operating techniques used with the dredge.

Sediment resuspension can be lessened by changing operating techniques, as in the case of the cutterhead, or by modifying the equipment, such as enclosing a clamshell bucket. Special purpose dredges can also be used to reduce sediment resuspension, but their lower production rates limit their application.

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## PREFACE

This work was conducted under the Dredging Contaminated Sediments Work Unit as part of the Improvement of Operations and Maintenance Techniques (IOMT) Program at the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The IOMT Program is sponsored by the Office, Chief of Engineers (OCE), U. S. Army, with overall program management assigned to the WES Hydraulics Laboratory (HL). This specific work unit was further assigned to the WES Environmental Laboratory (EL) and managed through the Environmental Effects of Dredging Programs (EEDP).

The work was conducted by MAJ Gene L. Raymond, Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), EL, under the direct supervision of Mr. Michael R. Palermo, Chief, WREG; and Dr. Raymond L. Montgomery, Special Assistant, EED; and under the general supervision of Mr. Andrew J. Green, Chief, EED; and Dr. John Harrison, Chief, EL. Program Manager for the IOMT was Mr. Richard A. Sager, HL, and Program Manager for the EEDP was Mr. Charles C. Calhoun, Jr., EL. Messrs. J. Gottesman and Charles Hummer were the OCE Technical Monitors.

Commander and Director of WES during the preparation of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

Raymond, G. L. 1984. "Techniques to Reduce the Sediment Resuspension Caused by Dredging," Miscellaneous Paper HL-84-3, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)  
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres

# TECHNIQUES TO REDUCE THE SEDIMENT RESUSPENSION CAUSED BY DREDGING

## PART I: INTRODUCTION

### Background

1. During the last 100 years, the sediments of the Nation's waterways have increasingly become repositories for a variety of contaminants. This contamination is a result of river commerce, industrial activities, widespread use of pesticides in agriculture, and intentional or inadvertent dumping of pollutants. Regardless of the source of pollution, today's dredging activities frequently must be conducted within this contaminated environment. However, dredging equipment and practices in the United States evolved in an era when the major emphasis was to achieve the greatest possible economic returns through maximizing production, with only secondary consideration given to environmental impacts. As a result, conventional dredges are not specifically designed for operation in highly contaminated sediments. Therefore, some modification of either existing equipment or operating methods may be necessary when dredging highly contaminated sediments.

2. Sediments become contaminated because of the affinity of contaminants, particularly chlorinated hydrocarbon pesticides and polychlorinated biphenyls (PCBs), for the clay-sized particles and natural organic solids found in most river sediments. When sediments are disturbed, such as during dredging operations, contaminants may be transferred to the water column either through resuspension of the sediment solids, dispersal of interstitial water, or desorption from the resuspended solids. Investigations by Fulk, Gruber, and Wullschleger (1975) showed that, for sediment concentrations of less than 100 g/l, the amount of pesticides and PCBs that are dissolved or desorbed into the water column from the resuspended sediment is negligible. They determined that basically all contaminants transferred to the water column were due to the resuspension of solids. They also reported that the reduction of suspended solids concentrations due to settling resulted in a decrease in contaminant concentrations. The spread of contaminants during dredging operations is therefore linked to the resuspension of sediments, particularly clay-sized and organic particles.

3. In addition to the concern of conducting dredging operations in

contaminated sediments, Federal, state, and local environmental regulatory agencies have set standards for the resuspension of sediments in general. The resuspension of sediments is usually referred to in the regulations in terms of turbidity, which is an optical term describing the cloudy appearance of water. Regulatory standards for turbidity are usually motivated by a concern for the suspected effects of suspended material on aquatic plants or animals.

4. The U. S. Army Engineer Waterways Experiment Station (WES) has initiated studies to determine the relative effectiveness of various methods of dredging contaminated sediments. These studies are being conducted as part of the Improvement of Operation and Maintenance Techniques (IOMT) Program. The specific environmental concerns addressed include resuspension of contaminated sediments and the possibility of contaminant release during the dredging operation. This question of dredging in contaminated sediments is being addressed in three ways: the assembly and evaluation of available domestic and foreign information concerning sediment resuspension and contaminant release, the development of appropriate laboratory tests to predict contaminant release from resuspended sediments, and the use of field studies to monitor performance and compare dredges operating under various conditions.

#### Purpose and Scope

5. The purpose of this paper is to present the findings from ongoing research efforts. It will discuss the sediment resuspension characteristics of various conventional dredges, provide a comparison between the dredge types with respect to sediment resuspension and water column effects, and present methods for limiting the sediments resuspended by conventional dredges. Several special-purpose dredges that may have potential to limit sediment resuspension are also introduced. This report is based on an extensive review of foreign and domestic information on sediment resuspensions due to dredging and on the results of field studies conducted under the IOMT Program.

## PART II: SEDIMENT RESUSPENSION FROM DREDGING

### Nature of Resuspended Sediment

6. Investigations by Wechsler and Cogley (1977) found that the material resuspended during dredging consists primarily of silt, clay, and organics. This resuspended material is sometimes referred to in terms of turbidity. While turbidity, which describes an optical property of water, can give an indication of the extent of sediment resuspension, it cannot be used to quantitatively describe the amount of resuspended sediments. Turbidity cannot be consistently correlated with weight concentration of suspended matter because the optically important factors of size, shape, and refractive index of the particulate materials bear little relationship to the concentration and specific gravity of the suspended matter. Turbidity cannot be used to tell which grain sizes contribute most to the resuspension problem. Therefore, whenever possible, comparisons of dredge resuspension will be made in terms of suspended solids as determined by gravimetric analysis.

7. Wechsler and Cogley (1977) reported that the coarse-grained fractions ( $>74\ \mu$ ) settle rapidly under normal conditions of water turbulence and thus do not contribute significantly to the turbid appearance of water. Silt comprises the nonclay mineral fraction of sediment and has a grain size of 2 to  $74\ \mu$ . Although silt particles, with settling rates as low as 1 cm/hr, may contribute to turbidity, in most cases the clay fraction and the organic matter are mainly responsible for the turbid appearance of water in the vicinity of dredging operations.

8. Extensive reviews of the literature concerning sediment resuspension caused by dredging were conducted by Barnard in 1978 and more recently by Herbach and Brahme (in press). They found that most conventional dredges create low-solids-concentration plumes of silt- and clay-sized particles or small flocs that settle through the water column at very slow rates. Although the solids concentration in the water column in the vicinity of the dredging operation usually does not exceed several hundred milligrams per litre, the particles continue to settle until the solids concentration near the bottom can exceed 10 g/l. Barnard (1978) referred to this level of solids concentration (0 to 10 g/l) as turbidity (Figure 1). Higher concentrations take on the properties of fluid mud. Barnard noted that the nature, degree, and extent

DREDGED MATERIAL SUSPENSIONS			
QUALITATIVE DESCRIPTOR	PROCESSES	SOLIDS CONCENTRATION (g/l) AVERAGE (RANGE)	BULK DENSITY (g/cc)* AVERAGE (RANGE)
TURBIDITY		0 g/l	1.000
	↑	↑	↑
LOW DENSITY	INDEPENDENT SETTLING	10 g/l (5-20)	1.006 (1.003-1.012)
FLUID MUD	↓	↓	↓
HIGH DENSITY	HINDERED OR ZONE SETTLING	200 g/l (175-225)	1.125 (1.109-1.140)
TYPICAL BOTTOM SEDIMENT	↑	↑	↑
	SELF-WEIGHT CONSOLIDATION	400 g/l (300-500)	1.249 (1.187-1.311)
	↓	↓	↓

\*ASSUME SOLIDS = 2.65 g/cc  
WATER = 1.00 g/cc

Figure 1. Characteristics of suspended solids in the water column in the vicinity of dredging and disposal operations (Barnard 1978)

of sediment resuspension are controlled by many factors, including characteristics of the sediment, hydrologic regime, and hydrodynamic forces.

#### Characteristics of Various Dredges

9. In addition to the characteristics of sediments that contribute to resuspension, different types of dredges generate different levels of resuspended sediment. Both the type of equipment and the operating techniques used with the equipment are important. This section will discuss some of the commonly used dredges and their potential for causing sediment resuspension during operations.

##### Cutterhead dredges

10. The cutterhead dredge is basically a hydraulic suction pipe combined with a cutter to loosen material that is too consolidated to be removed by suction alone (Figure 2). This combination of mechanical and hydraulic systems makes the cutterhead one of the most versatile and widely used dredging systems; however, its use also increases the potential for sediment resuspension. While a properly designed cutter will cut and guide the bottom material toward the suction efficiently, the cutting action and the turbulence associated with the rotation of the cutter resuspend a portion of the bottom material. The level of sediment resuspension is directly related to the type

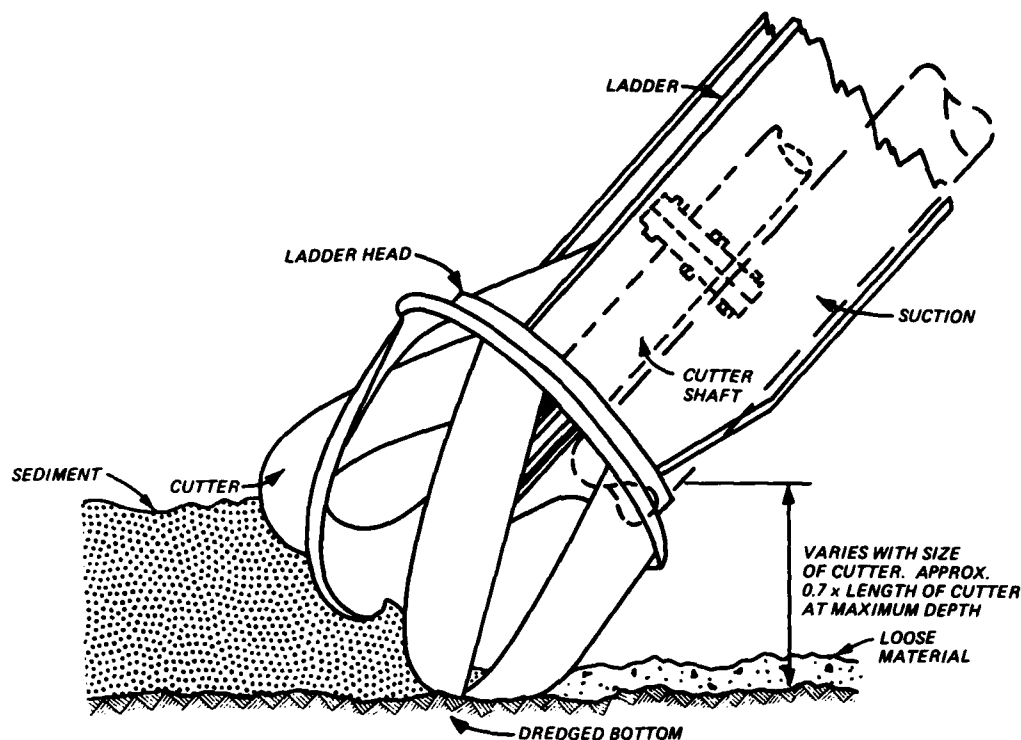


Figure 2. Cross-sectional view of typical cutterhead suction dredgehead (Huston and Huston 1976)

and quantity of material cut but not picked up by the suction. The ability of the dredge's suction to pick up bottom material determines the amount of cut material that remains on the bottom or is resuspended.

11. While little experimental work on cutterhead resuspension has been done, there have been several field studies that attempted to identify the extent of cutterhead resuspension. Barnard (1978), reporting on the field investigations of Huston and Huston (1976) and Yagi et al. (1975), stated that, based on the limited field data collected under low-current speed conditions, elevated levels of suspended material appear to be localized in the immediate vicinity of the cutter as the dredge swings back and forth across the dredging site. Barnard (1978) stated that within 10 ft\* of the cutter, suspended solids concentrations are highly variable, but may be as high as a few tens of grams per litre; these concentrations decrease exponentially with

\* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

depth from the cutter to the water surface. Near-bottom suspended solids concentrations may be elevated to levels of a few hundred milligrams per litre at distances of 1000 ft from the cutter.

12. Recent field tests and literature reviews by WES have found cutter-head resuspension to be substantially less than discussed by Barnard. Sediment resuspension within 50 ft of the cutter has seldom been found to exceed 1000 mg/l. Figure 3 is a schematic representation of average suspended

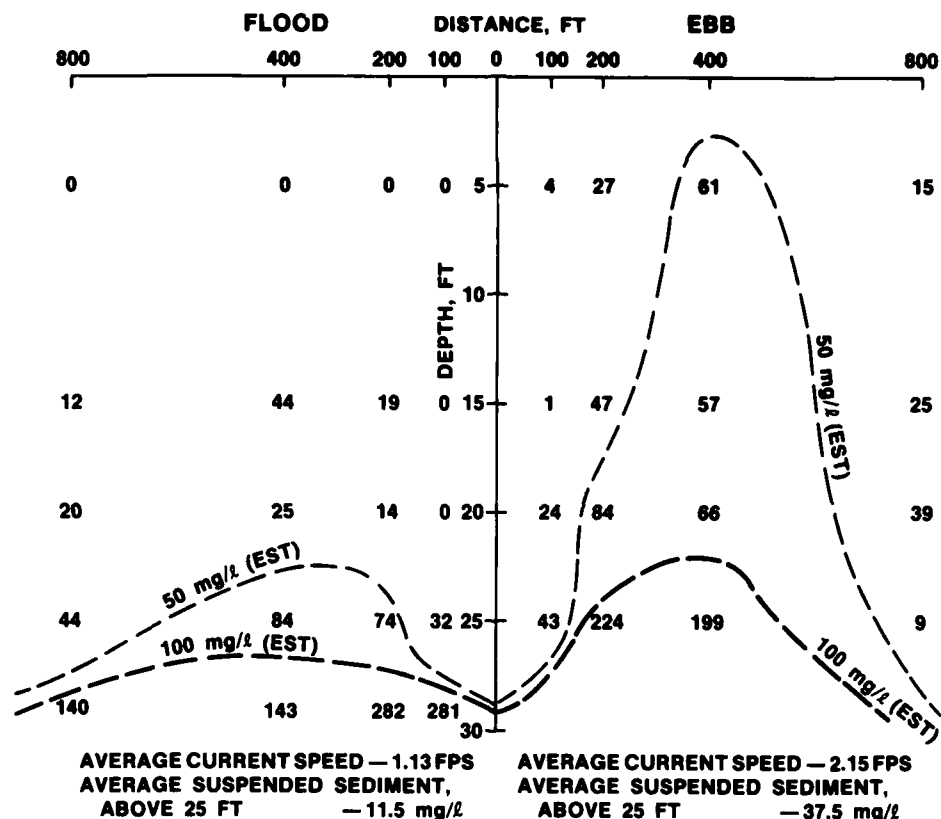


Figure 3. Schematic representation of average suspended sediment value for indicated depths and distances, James River cutterhead test

sediment values observed during an 18-in. cutterhead operation in the James River (Raymond in preparation). These values are a 4-day average and represent the actual suspended sediment levels, as determined by gravimetric analysis, less the background suspended sediment levels for the appropriate depth and current speed. Therefore, a value of zero means there is no increase above background, not that the level of suspended sediment is zero. This



figure highlights several characteristics of cutterhead dredges. First, as pointed out by Barnard (1978) and Herbach and Brahme (in press), and suggested by intuition, depth has an important correlation to suspended sediment level. Secondly, even though the plume of resuspended material has its source at the bottom, some material appears to move upward surprisingly fast. This upward movement is probably connected to the action of the cutter. Finally, the effect of the different average ambient current speeds can be seen. The higher current speed at ebb tide appears to propel the resuspended sediments higher in the water column, thus making the overall average suspended sediment values higher for the ebb than the flood. The salinity was similar during both phases and well below the level required to produce stratification. The average suspended sediment values of the flood and ebb for the upper water column (25-ft level and above) are 11.5 mg/l and 37.5 mg/l, respectively. This difference is statistically significant at the 95-percent confidence level. In this case, the effects of dredging in higher current velocity will be magnified over that of lower current velocities. It appears that for current speeds in the 2-fps range the sediment was sufficiently hindered to prevent the settling rate that occurred at the lower current velocities. This effect cannot be confirmed in the lower water column however.

#### Hopper dredges

13. Hopper dredges are used mainly for maintenance dredging in bar areas and shipping channels where traffic and operating conditions rule out the use of stationary dredges. As the dredge moves forward, the bottom sediment is hydraulically lifted from the channel bottom with a draghead, transported up the dragarm (i.e., trailing suction pipe), and temporarily stored in hopper bins in the ship's hull. Most modern hopper dredges have one or two dragarms mounted on the side of the dredge and have storage capacities ranging from several hundred to over 12,000 cu yd. During the filling operation, pumping of the dredged material slurry into the hoppers is often continued after the hoppers have been filled in order to maximize the amount of high-density material in the hopper. The low-density turbid water at the surface of the filled hoppers then overflows and is usually discharged through ports located near the waterline of the dredge. Resuspension of fine-grained sediment during hopper dredge operations is caused by the dragheads as they are pulled through the sediment, the turbulence generated by the vessel and its prop wash, and the overflow of turbid water during hopper filling operations.

14. Field data confirm that the suspended solids levels generated by a hopper dredge operation are primarily caused by hopper overflow in the near-surface water and draghead resuspension in near-bottom water. In the immediate vicinity of the dredge, a well-defined upper plume is generated by the overflow process and a near-bottom plume by draghead resuspension; 900 to 1200 ft behind the dredge, the two plumes merge into a single plume (Figure 4). As the distance from the dredge increases, the suspended solids

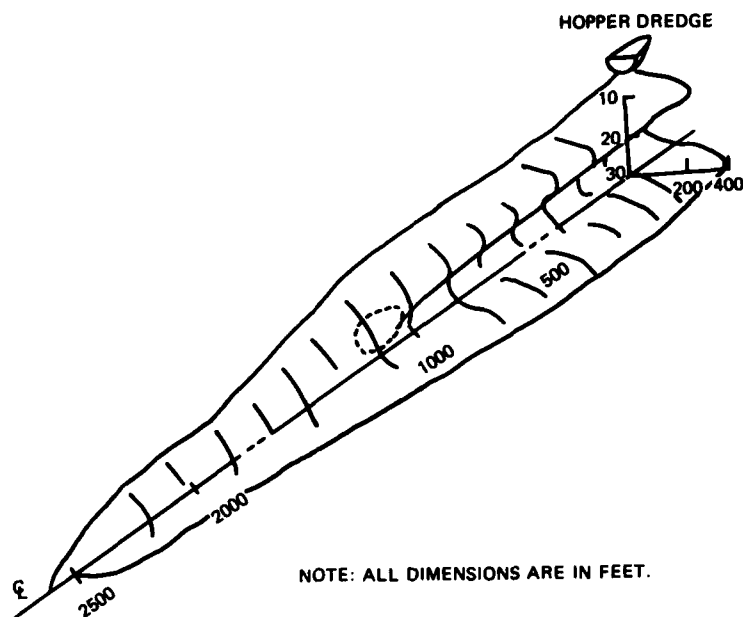


Figure 4. Postulated double plume resulting from hopper dredge operations (Barnard 1978)

concentration in the plume generally decreases, and the plume becomes increasingly limited to the near-bottom waters. Suspended solids concentrations may be as high as several tens of grams per litre near the discharge port and as high as a few grams per litre near the draghead. Suspended sediment levels in the near-surface plume appear to decrease exponentially with increasing distance from the dredge due to settling and dispersion, and the levels quickly reach concentrations of less than 1 g/l. However, plume concentrations may exceed background levels even at distances in excess of 3600 ft (Barnard 1978).

#### Bucket dredges

15. The bucket dredge consists of various types of buckets operated from a crane or derrick mounted on a barge or on land. These dredges are used

extensively for removing relatively small volumes of material, particularly around docks and piers or within restricted areas. The sediment removed is at nearly in situ density; however, the production rates are quite low compared to that for a cutterhead dredge, especially in consolidated material. The dredging depth is practically unlimited, but the production rate drops with increases in depth. The bucket dredge usually leaves an irregular, cratered bottom. The resuspension of sediments during bucket dredging is caused primarily by the impact, penetration, and withdrawal of the bucket from the bottom sediments. The effect of this material is usually limited to the near bottom. Secondary causes are loss of material from the bucket as it is pulled through the water, spillage of turbid water from the top and through the jaws of the bucket as it breaks the surface, and inadvertent spillage while dumping. This secondary loss material affects the entire water column.

16. Limited field measurements of sediment resuspension caused by bucket dredges showed that the plume downstream of a typical bucket operation may extend approximately 1000 ft at the surface and 1500 ft near the bottom. It was also observed that the maximum suspended sediment concentration in the immediate vicinity of the dredging operation was less than 500 mg/l and decreased rapidly with distance from the operation due to settling and mixing effects (Barnard 1978). Field studies concluded by WES in the St. Johns River around a 13-cu-yd clamshell bucket operation show the effect of the clamshell bucket on the water column (Raymond 1983). Figure 5 shows the sample locations used to collect the sediment resuspension data. Figure 6 is a schematic representation of the data collected along radials 1 and 2. The suspended sediment values were determined by gravimetric analysis and have had the background values deducted. The current speeds were low, with no difference between radials. Radial 3 is not shown since it represents a more shallow, backwater type area. Here again it can be seen that the greater sediment resuspension is at the bottom. However, elevated levels of suspended sediment reach almost to the surface, as shown by the 50-mg/l line, even under low current conditions.

#### Dustpan dredges

17. The dustpan dredge is a hydraulic suction dredge that uses a widely flared dredgehead along which water jets are mounted. The jets loosen and agitate the sediments, which are then captured in the dustpan head as the dredge moves forward. This type of dredge works best in free-flowing granular material and is not suited for use in fine-grained clay sediments. During

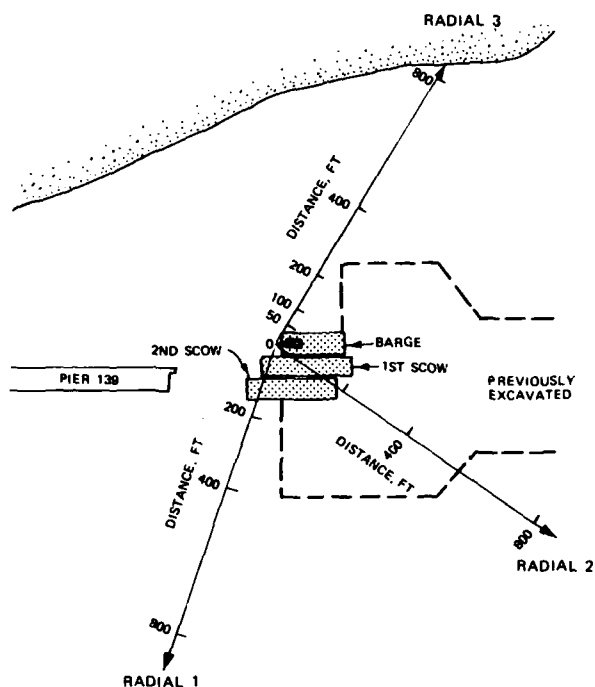


Figure 5. Locations of radials and sampling points along the radials used for the Jacksonville clamshell comparison tests (Raymond 1983)

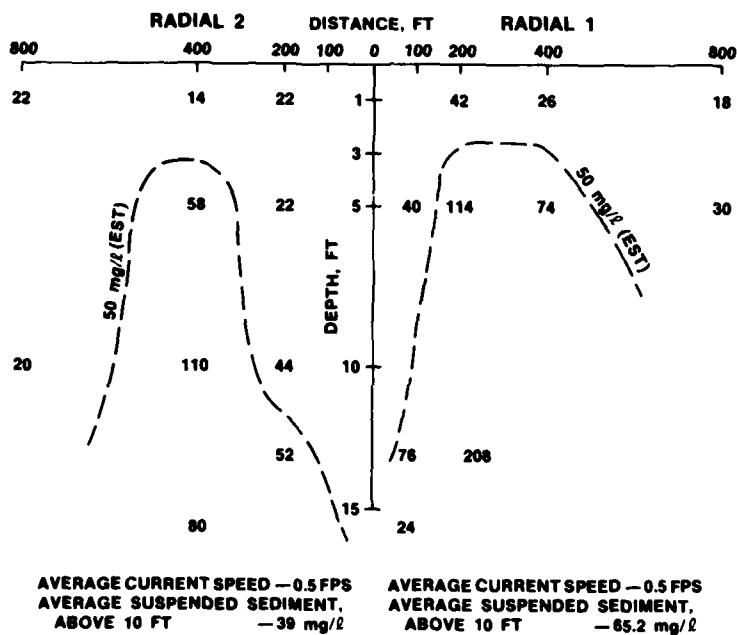


Figure 6. Schematic representation of average suspended sediment levels for indicated distances and depths, Jacksonville clamshell comparison (constructed from data in Raymond in preparation)

1982, an experiment was conducted in the fine-grained sediments of the James River using a modified dustpan head (without water jets). The dustpan head and a conventional cutterhead were operated in the same reach of the James River for comparison purposes. It was hoped that the dustpan head, using suction only, could excavate thin layers of contaminated clay sediment with less resuspension than a cutterhead. However, the dustpan head experienced repeated clogging and produced at least as much resuspension as a cutterhead operating in the same material (Raymond 1983).

#### Comparison of Dredge Resuspension

18. When planning a dredging operation, the project engineer may be faced with the problem of selecting the best dredge based on the cost and availability of different dredges, the operating conditions at the project site, the material to be dredged, the job specifications, and the various environmental considerations. Since each dredging/disposal project is site-specific, a dredge that might be ideal in one situation may not be suitable for another. The production rate of a given dredge relative to the levels of turbidity that may be generated, the duration of the project, and the background levels of suspended sediment and contamination should all be considered when evaluating the potential impact of different sizes and types of dredges.

19. It is important to remember that a sophisticated and expensive dredging system will not necessarily eliminate all sediment resuspension. In addition, it is imperative to concurrently consider the compatibility of all the phases of the dredging operation (excavation, transportation, and disposal) as a total, integrated system and not as separate components. The relative impact of each operation must be objectively evaluated relative to its cost and overall benefits.

20. The results of field studies may provide some insight into dredge selection when limiting sediment resuspension is an important factor. Wakeman, Sustar, and Dickson (1975), based on their work in San Francisco Bay, state "the cutterhead dredge seems to have the least effect on water quality during the dredging operation. This is followed by the hopper dredge without overflow. The clamshell dredge and hopper dredge during overflow periods both can produce elevated levels of suspended solids in the water column." Herbich and Brahme (in press), discussing comparisons of the sediment

resuspension potential of different dredges operating in clay, found that the trailing suction dredge (without overflow) and the cutterhead dredge had a similar resuspension potential, while the clamshell dredge was determined to produce about two and a half times as much resuspension. Field tests conducted by Raymond (1983) also support this ranking. The following tabulation was constructed from Raymond's test results and summarizes the effects of a clamshell bucket dredge and a cutterhead dredge operating in similar fine-grained sediments.

<u>Dredge Type</u>	<u>Resuspended Sediment, mg/l</u>	
	<u>Upper Water Column</u>	<u>Near Bottom</u>
Cutterhead	34.6	133.5
Clamshell	105.9	134.3

These data were normalized with respect to hydrodynamic conditions and background levels of suspended sediment. The values represent the average of all samples taken within 800 ft of the dredge along similar radials. The tabulation shows that while the effect of the cutterhead and the clamshell are similar at near-bottom levels (1 to 5 ft from the bottom), the cutterhead's effect is much less than the clamshell's in the upper water column. This can also be seen by comparing the 50-mg/l lines shown in Figures 3 and 6. Figure 7 is the average of the suspended sediment values shown in Figures 3 and 6, with the clamshell bucket values shown in parentheses. We see that the cutterhead exceeds 50 mg/l only near the bottom, and its effect is barely detectable above 5 ft. The clamshell bucket effects can be seen up to the surface. Thus, the clamshell affects a greater portion of the water column to a greater extent than does the cutterhead.

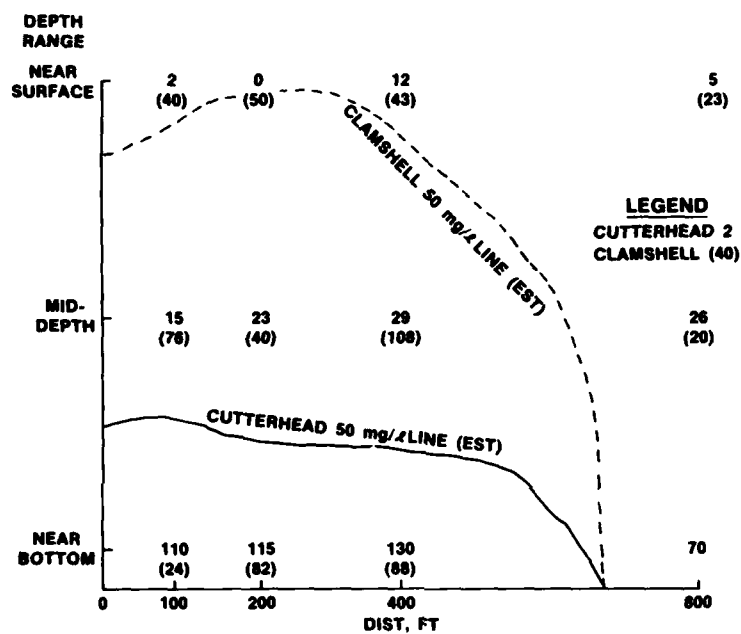


Figure 7. Comparison of average suspended sediment values for a cutterhead operation and a clamshell operation. Values without parentheses are for the cutterhead; values within parentheses are for the clamshell

### PART III: LIMITING SEDIMENT RESUSPENSION

#### Cutterhead Dredge Operations

21. As pointed out by Barnard (1978) and Huston and Huston (1976), the sediment resuspended by cutterhead excavation is dependent on the operating techniques used. Indeed, the cutterhead may be the most sensitive of any dredge type to changes in operating techniques. Barnard (1978) stated that the sediment resuspended by the cutter of a cutterhead dredge apparently increases exponentially as thickness of cut, rate of swing, and cutter rotation rate increase. Although suspended solids levels around the cutter also increase with increasing rates of production, it is possible to maximize the production rate of the dredge without resuspending excessive amounts of bottom sediment. Herbich and Brahme (in press), reporting on Japanese studies, also identify the cutter's revolutions per minute, swing speed, and thickness of material cut as important factors in determining the level of sediment resuspension.

22. Although many researchers have commented on the importance of these operating factors, few have tried to quantify them. Yagi et al. (1975) and Shiba and Koba (in press) felt that increasing the depth of cut would also increase the sediment resuspension. However, efficiency experiments (i.e., energy required to produce a given output) conducted by Slotta, Joanknecht, and Emrich (1977) showed that the greatest production and efficiency came from deeper, rather than shallow cuts (a 45-deg ladder depression versus a 20-deg ladder depression for the same depth). Yagi et al. (1975); Shiba and Koba (in press); and Kaneko, Watari, and Aritomi (in press) all found that the greater the swing speed, the greater the sediment resuspension. They found this particularly to be true of swing speeds above 0.5 fps. Slotta, Joanknecht, and Emrich (1977) found the most efficient swing speed to be 0.3 fps. Finally, all of the above authors found cutter revolutions per minute (cutter speed) to be a factor; however, only Shiba and Koba, based on their testing, stated that this was the major factor. None of the authors attempted to quantify a minimum cutter speed; however, Slotta, Joanknecht, and Emrich did find that a cutter speed of 30 revolutions per minute was the most efficient. Finally, both Yagi et al. (1975) and Kaneko, Watari, and Aritomi (in press) reported that by using the suction without rotating the cutter, resuspension could be reduced by about one half.



### Operational controls

23. Based on the impact of the factors described above, Huston and Huston (1976) recommend the following operational controls to limit levels of sediment resuspension. These controls will reduce the amount of material disturbed by the cutterhead but not entrained by the suction:

- a. Large sets and very thick cuts should be avoided since they tend to bury the cutterhead and may cause high levels of resuspension if the suction cannot pick up all of the dislodged material.
- b. The leverman should swing the dredge so that the cutterhead will cover as much of the bottom as possible. This minimizes the formation of windrows or ridges of partially disturbed material between the cuts; these windrows tend to slough into the cuts and the material in the windrows may be susceptible to resuspension by ambient currents and turbulence caused by the cutterhead. Windrow formation can be eliminated by swinging the dredge in close concentric arcs over the dredging area. This may involve either modifying the basic stepping methods used to advance the dredge or using a Waggoner or spud carriage system.
- c. Side slopes of channels are usually dredged by making a vertical box cut; the material on the upper half of the cut then sloughs to the specified slope with associated resuspension. The specified slope should be cut by making a series of smaller boxes. This method, called "stepping" the slope, will not eliminate all sloughing, but will help to reduce it.
- d. On some dredging projects, it may be more economical to roughly cut and remove most of the material, leaving a relatively thin layer for final cleanup after the project has been roughed out. However, this remaining material may be subject to resuspension by ambient currents or prop wash from passing ship traffic.
- e. When layer cutting is used, the dredge will remove a single layer of material over a large portion of the channel; the dredge is then set back to dredge another layer. This continues down to the required depth of the project. Since loose material is often left on the bottom after each layer is dredged, this technique should only be used where resuspension of the remaining material will not create sediment resuspension problems.

### Equipment design considerations

24. Design of the cutterhead greatly influences the dredge's production and sediment resuspension during the dredging process. The dredge's suction (Figure 2), which picks up the material that has been cut by the cutter, can be partially responsible for sediment resuspension around the cutter if the energy provided to the suction by the dredge pump is not great enough

to cause the suction to pick up all of the material disturbed by the cutter. Water-jet booster systems or ladder-mounted submerged pumps installed on cutterhead dredges have been found to enhance the dredge's pickup capability, increase slurry density and potential production rate, and decrease the generation of suspended solids (Barnard 1978).

25. The shape of the cutterhead also affects the sediment resuspended, particularly if no overdepth is allowed. The cutterheads shown in Figure 8

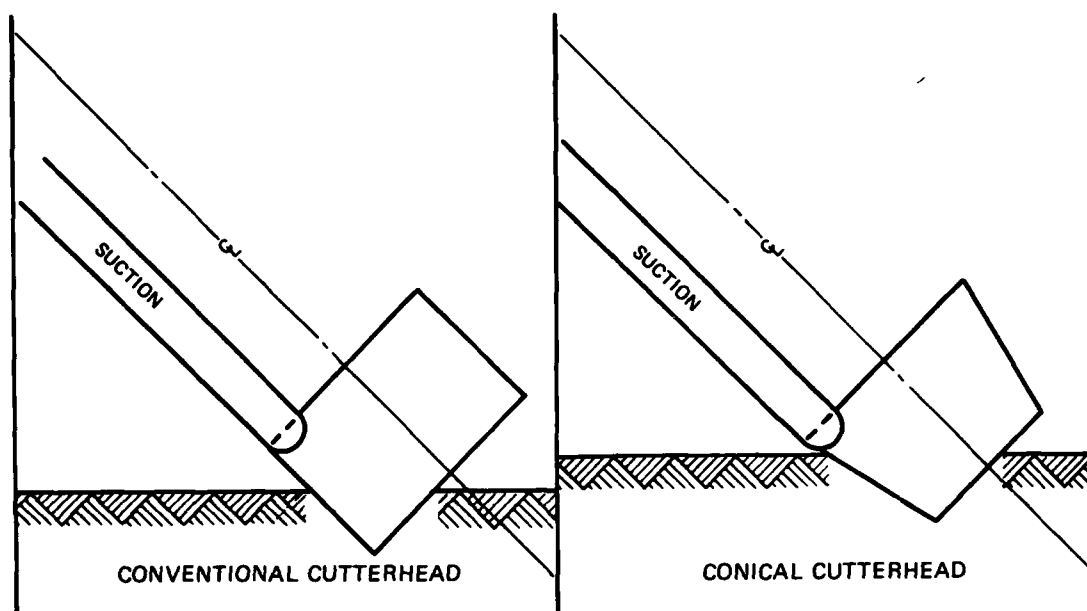
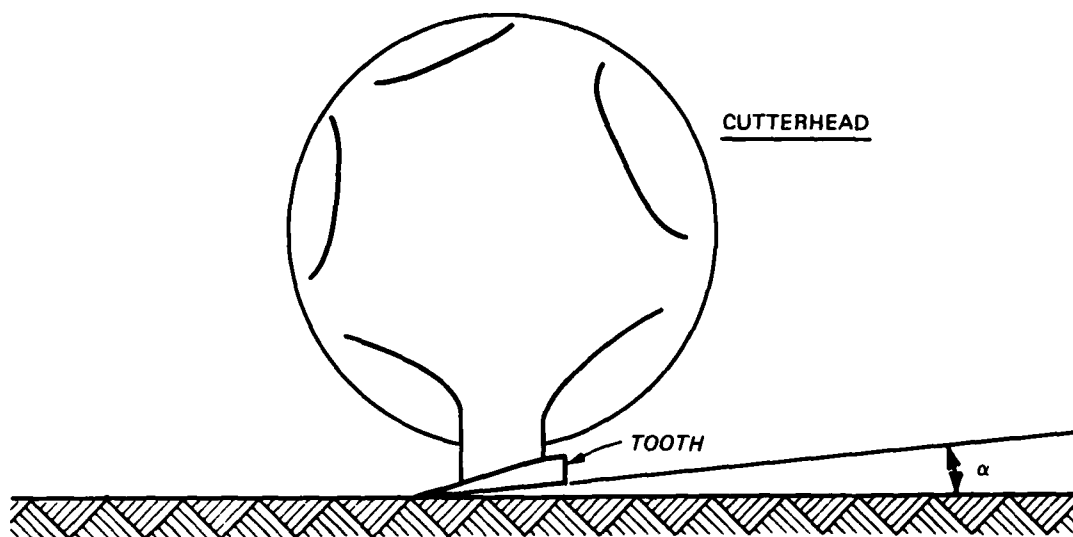


Figure 8. Effect of cutterhead shape on suction height above the bottom

have the same length and base width. They are also depressed to the same angle and are buried to the same depth. However, with the conical-shaped head, the suction is brought closer to the material and the chance of entrainment by the suction is improved. This shape difference would be particularly important if the head was not completely buried.\*

26. The angle  $\alpha$  in Figure 9 is called the rake angle. If the rake angle is too large, it will cause a gouging action that will sling soft fine-grained material outward. If the rake angle is too small, heeling (the

\* Personal communication from Thomas M. Turner, Turner Consulting, Inc., Sarasota, Fla., March 1983. Mr. Turner also provided sketches for Figures 8 and 9. See also WES Environmental Laboratory files (WESEE) Memorandum for Record, 15 April 1983, Subject: Equipment Aspects of Dredging Contaminated Sediments.



RAKE ANGLE  $\alpha$

Figure 9. Schematic front view of a cutterhead showing the cutter tooth rake angle

striking of the bottom with the heel of the tooth) will occur, increasing resuspension. For fine-grained maintenance-type material, a rake angle of from 20 to 25 deg would be best. This would allow a shallow entry that would lift the bottom sediment and guide it toward the suction.\*

#### Hopper Dredge Operations

27. Of the two hopper-dredge sources of sediment resuspensions mentioned earlier, draghead overflow and pumping past overflow, the overflow of material from the hopper produced by far the most sediment resuspension. This source of near-surface resuspension can be addressed in several ways. The first is to assess the type material being dredged and its environmental impact. If the material being dredged is clean sand, the percentage of solids in the overflow will be small and economic loading may be achieved by pumping past overflow. When contaminated sediments are to be dredged and adverse environmental effects have been identified, pumping past overflow is not recommended. In such cases, other types of dredges may be more suitable for

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\* Ibid.

removing the contaminated sediments from the channel prism. In the case of fine-grained materials, the settling properties of silt and clay sediments may be such that only a minimal load increase would be achieved by pumping past overflow (Headquarters, Department of the Army (HQDA) 1983).

28. Another approach has been suggested by the Japanese. They have developed a relatively simple submerged discharge system for hopper dredge overflow, called the Anti-Turbidity Overflow System (ATOS) (Herbich and Brahme in press). The overflow collection system in the dredge was streamlined to minimize incorporation of air bubbles, and the overflow chutes were moved from the sides to the bottom of the dredge's hull (Figure 10). With this arrangement, the discharge descends rapidly to the bottom with a minimum amount of dispersion within the water column. The system can be incorporated in existing dredges through modifications of their overflow systems. This system has been successfully incorporated in three Japanese trailing-hopper dredges with capacities ranging from 2500 to 5000 cu yd. Tests carried out on

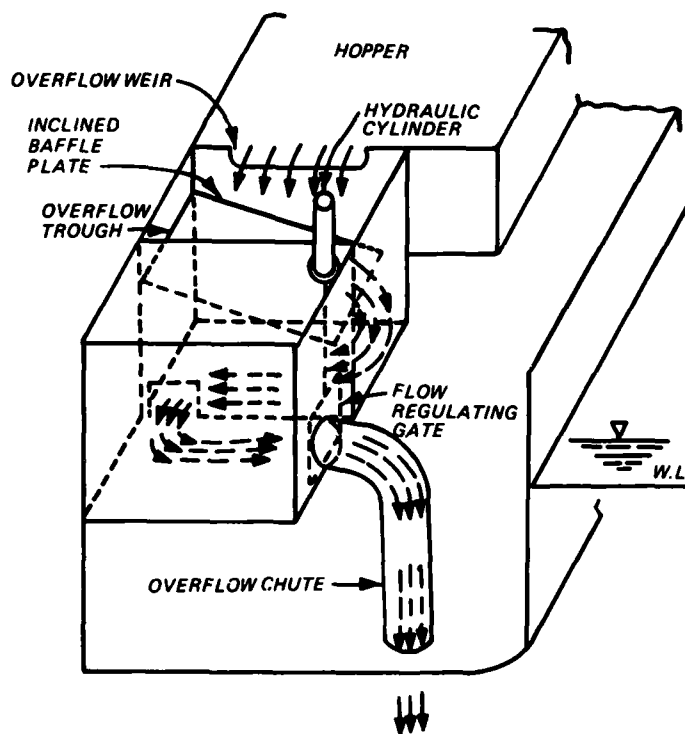


Figure 10. Schematic drawing of a hopper dredge bin equipped with the Japanese designed Anti-Turbidity Overflow System (ATOS) (Herbich and Brahme in press)

the dredge KAIRYU MARU indicated considerable reduction in sediment resuspension at the surface and 3 ft below the surface both beside the ship and 100 ft behind the ship. The data comparing the sediment resuspended by a conventional overflow system and by the ATOS are shown below:

<u>Sampling Location</u>	Average Concentration of Suspended Solids, mg/l			
	<u>Conventional System</u>		<u>ATOS</u>	
	<u>Surface</u>	<u>3 ft below Surface</u>	<u>Surface</u>	<u>3 ft below Surface</u>
Beside ship	627	272	6.0	8.0
100 ft aft of ship	119	110	6.5	8.9

It should be pointed out, however, that ATOS is intended only to reduce near-surface suspended solids, not the overall amount of suspended solids in the water column. The ATOS device has the effect of forcing the solids plume down to a lower level. This in itself can have the effect of limiting the areal extent of the resuspended solids.

#### Clamshell Bucket Dredge Operations

29. Although Japanese experimenters have reported some reduction in sediment resuspension with the variation of hoist speed and depth of cut, their greatest reduction in resuspension with clamshell dredging came from the use of a so-called "watertight" or enclosed clamshell bucket. The Port and Harbor Institute of Japan developed a watertight bucket in which the top is enclosed so that the dredged material is contained within the bucket. A direct comparison of a 1-cu-m standard open clamshell bucket with a watertight clamshell bucket indicates that watertight buckets generate 30 to 70 percent less resuspension in the water column than the open buckets (Barnard 1978).

30. A field test to compare the effectiveness of enclosed clamshell buckets was conducted by WES. The resuspension produced by an enclosed 13-cu-yd bucket was compared to a 12-cu-yd standard open bucket during dredging of the St. Johns River near Jacksonville, Fla. The results of this test are given in the tabulation on the following page.

Type of Clamshell Bucket	Sampling Radial	Average Suspended Sediment Level, mg/l*	
		Upper Water Column	Near Bottom**
Enclosed	1	27	233
	2	36	300
	3	81	N/A†
Open	1	123	147
	2	61	122
	3	133	N/A†

\* Average of all samples taken along the radial, adjusted for background suspended sediment level.

\*\* Measurements made within 5 ft of bottom.

† Average depth along this radial is 5 ft or less.

The sampling locations and radials used in this test were shown in Figure 5. Figure 11 shows the average suspended sediment levels at increasing depths along each radial. This test revealed a reduction in sediment resuspension in the upper water column with the enclosed bucket (Raymond 1983). Some drawbacks were also revealed however. The enclosed bucket produced increased resuspension near the bottom, probably due to a shock wave of water that precedes the watertight bucket due to the enclosed top. Also both the earlier Japanese and the Jacksonville buckets had rubber gaskets for seals along the cutting edge of the bucket. This limited the use of the bucket to soft material and trash-free areas. Current design concepts include the use of an interlocking tongue-and-groove edge to overcome the sealing problems.

31. Operationally, clamshell bucket resuspension can be lessened by ensuring the operator does not "drop" the bucket into the sediment but allows it to settle under its own weight, and by avoiding "sweeping." Sweeping is where the bucket is swung across the width of the cut to smooth the bottom and level off the high points. Sweeping occurs at the end of the cut prior to advancing to a new cut. Sweeping does help to level the irregular bottom that results from clamshell dredging; however, it also contributes significantly to sediment resuspension and should not be allowed when dredging contaminated sediments.

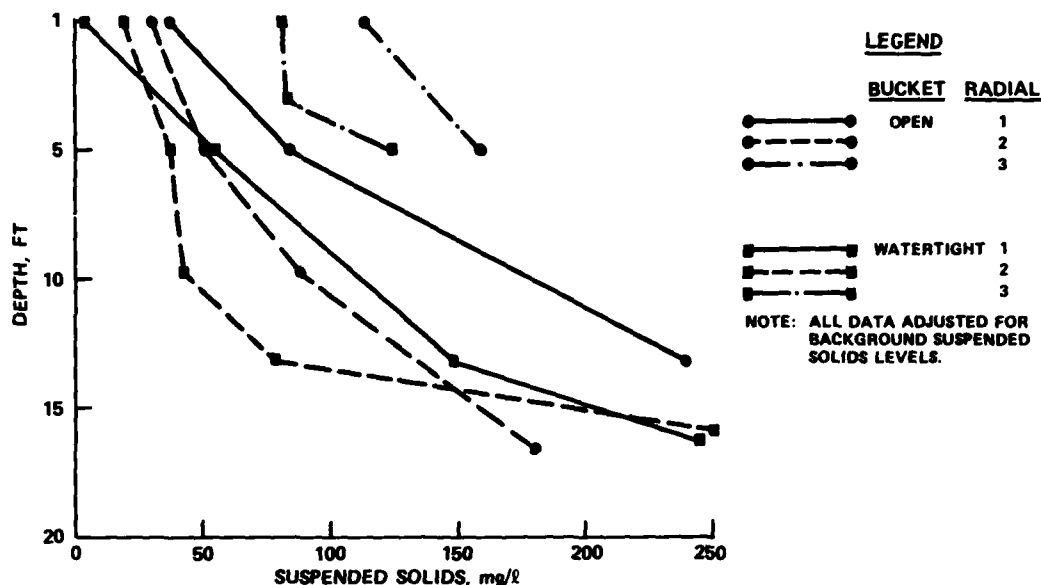


Figure 11. Average suspended sediment levels along sampling radials during clamshell dredging for Jacksonville comparison test. Data were adjusted for background conditions (from Raymond 1983)

### Special-Purpose Dredges

32. Special-purpose dredging systems have been developed during the last few years in the United States and overseas to pump dredged material slurry with a high solids content and/or to minimize the resuspension of sediments. Most of these systems are not intended for use on typical maintenance operations; however, they may provide alternative methods for unusual dredging projects such as in chemical hot spots. The special-purpose dredges that appear to have the most potential in limiting resuspension are shown in the following tabulation, which was taken from Herbach and Brahme (in press). A description of each dredge follows the tabulation.

<u>Name of Dredge</u>	<u>Suspended Sediment Level</u>
Pneuma pump	48 mg/l at 3 ft above bottom 4 mg/l at 23 ft above bottom (16 ft in front of pump)
Clean-Up System	1.1 to 7.0 mg/l at 10 ft above suction 1.7 to 3.5 mg/l at surface
Oozer pump	6 mg/l (background level) at 10 ft from head
Refresher System	4 to 23 mg/l at 10 ft from head

### Pneuma pump

33. The Pneuma pump was the first dredging system to use compressed air instead of centrifugal motion to pump slurry through a pipeline. It has been used extensively in Europe and Japan. According to the literature published by the manufacturer, this system can pump slurry at a relatively high solids content with little generation of turbidity. The operation principle is illustrated in Figure 12. During the dredging process, the pump is submerged

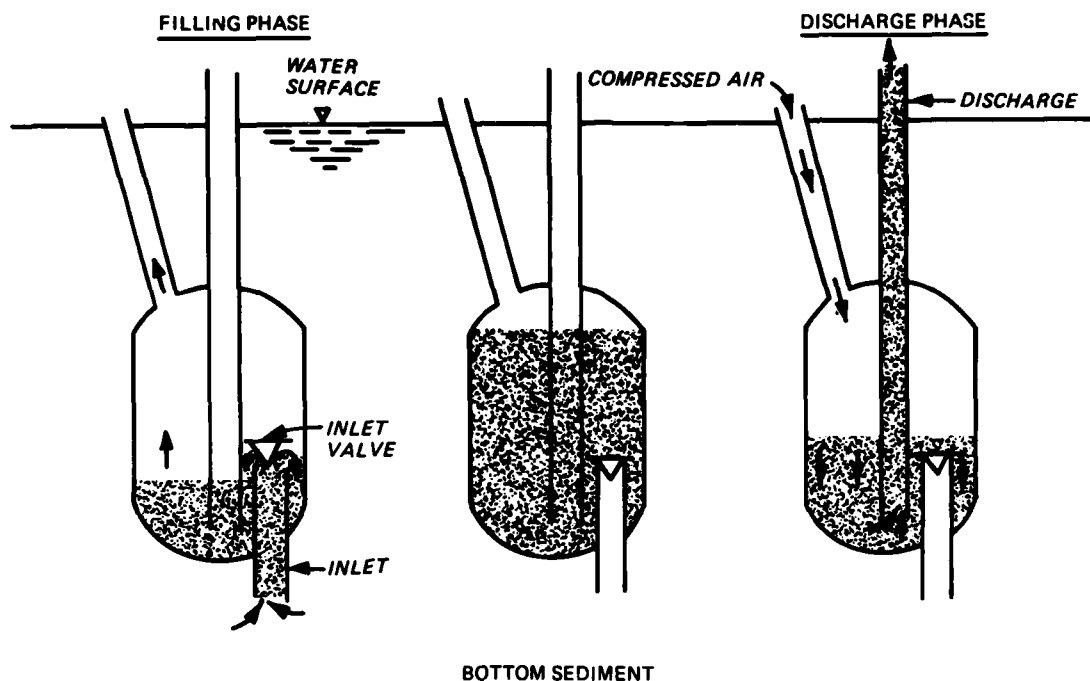


Figure 12. Operating cycle of Pneuma pump (from Barnard 1978)

and sediment and water are forced by hydrostatic pressure into one of the empty cylinders through an inlet valve. After the cylinder is filled, compressed air is supplied to the cylinder, forcing the water out through an outlet valve. When the cylinder is almost empty, air is released to the atmosphere, thus producing atmospheric pressure in the cylinder. A pressure difference occurs between the inside and outside of the cylinder, creating a pressure gradient that forces the sediment into the cylinder. When the cylinder is filled with sediment, compressed air is again pumped into the cylinder to expel the sediment from the cylinder. The capacity of a large plant (type 1500/200) is 2600 cu yd/hr. The system has been used in water depths of 150 ft; however, 500-ft depths are theoretically possible.



34. Field tests on a Pneuma model 600/100 were conducted by WES (Richardson et al. 1982). The results of turbidity monitoring, although not definitive, seemed to support the manufacturer's claim that the Pneuma pump generates a low level of turbidity when operated in loosely consolidated fine-grained sediments. It was also found that the Pneuma pump was able to dredge at almost in situ density in a loosely compacted silty clay typical of many estuarine sediments. The Pneuma pump, however, was not able to dredge sand at in situ density.

#### Clean-Up System

35. To avoid resuspension of sediment, Toa Harbor Works of Japan developed a unique Clean-Up System for dredging highly contaminated sediment (Sato 1976). The Clean-Up head consists of an auger that collects sediment as the dredge swings back and forth and guides it toward the suction of a submerged centrifugal pump (Figure 13). To minimize sediment resuspension, the auger is

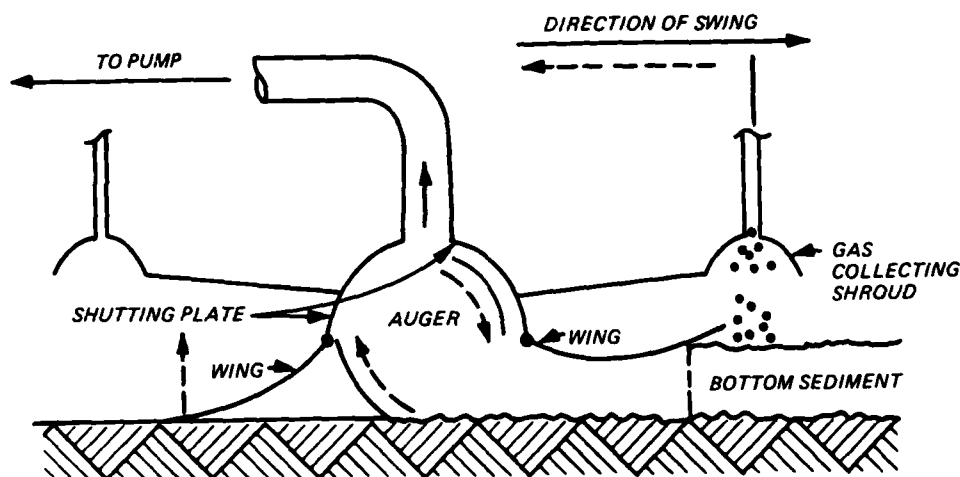


Figure 13. Clean-Up System dredgehead (from Barnard 1978)

covered by a movable wing that covers the sediment as it is being collected by the auger. Sonar devices indicate the elevation of the bottom. An underwater television camera is used to show the material being resuspended during a dredging operation. Suspended sediment concentrations around the Clean-Up System ranged from 1.7 to 3.5 mg/l at the surface to 1.1 to 7.0 mg/l at 10 ft above the suction equipment. Near-surface background levels were less than 4.0 mg/l (Herbich and Brahme in press).

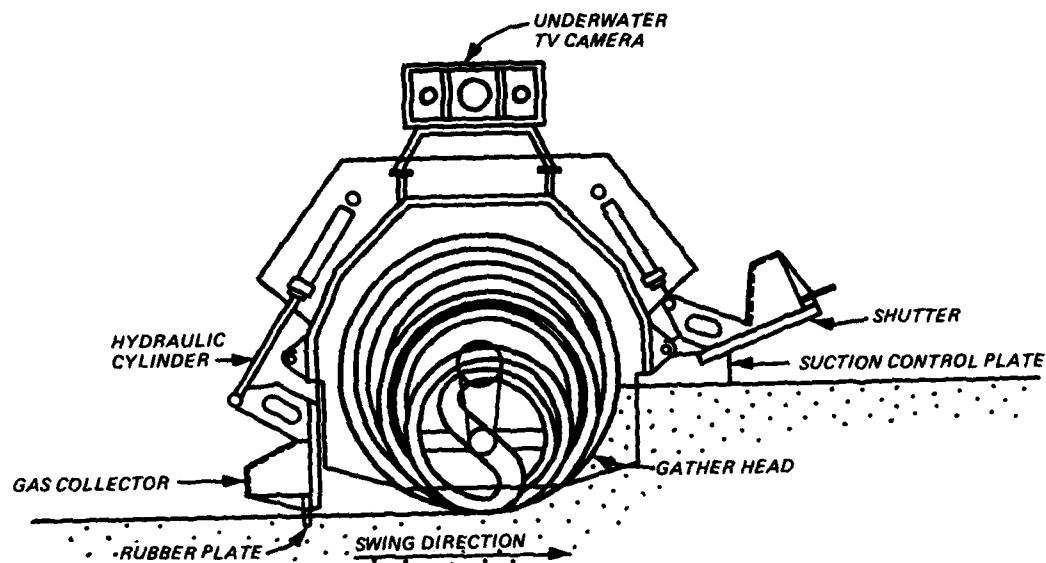
#### Oozer pump

36. The Oozer pump was developed by Toyo Construction Company, Japan.

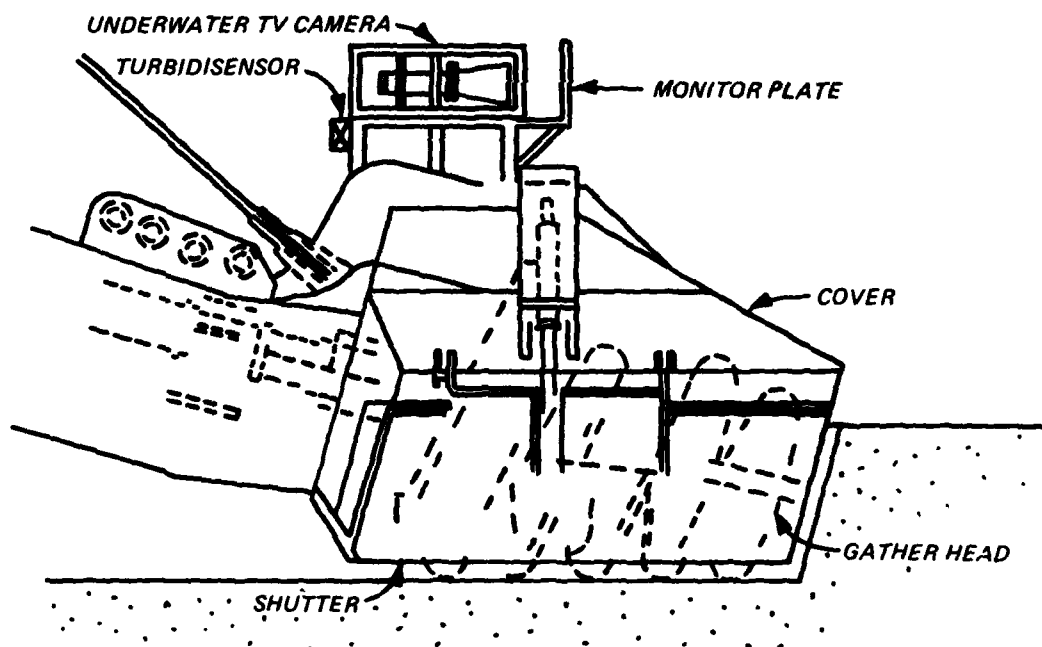
The pump operates in a manner similar to the Pneuma pump system; however, there are two cylinders (instead of three) and a vacuum is applied during the cylinder-filling stage to achieve more rapid filling of the cylinders. The pump is usually mounted on a dredge ladder and is equipped with special suction and cutterheads depending on the type of material being dredged. The conditions around the dredging system, such as the thickness of the sediment being dredged, the bottom elevation after dredging, and the amount of resuspension, are monitored by high-frequency acoustic sensors and an underwater television camera. A large Oozer pump has a dredging capacity ranging from 400 to 650 cu yd/hr. During one dredging operation, suspended solids levels within 10 ft of the dredging head were all within background concentrations of less than 6 mg/l (Herbich and Brahme in press).

#### Refresher System

37. Another system designed recently by the Japanese is the Refresher System. This system is an effort to modify the cutterhead hydraulic dredge. The Refresher uses a helical-shaped gather head to feed the sediments into the suction, with a cover over the head to reduce resuspension (see Figure 14). The Refresher also uses an articulated dredge ladder to keep the head level with the bottom over a wide range of dredging depths. During several tests in similar material, the Refresher System produced suspended sediment levels of from 4 to 23 mg/l within 10 ft of the dredge head as compared to 200 mg/l with a conventional cutterhead dredge. Production for the cutterhead (26-in. discharge) was 800 cu yd/hr while production with the Refresher System (17-in. discharge) was 350 cu yd/hr. The researchers felt that the Refresher System produced one fiftieth of the total resuspension produced by the operation of a cutterhead dredge (Kaneko, Watari, and Aritomi in press).



a. Front view



b. Side view

Figure 14. Front and side view of Japanese Refresher System  
(from Kaneko, Watari, and Aritomi in press)

## PART IV: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

38. Based on the results of the ongoing research, the following conclusions can be drawn:

- a. Dredging can cause the resuspension of contaminated sediments from the bottom into the water column. The sediments most likely to remain resuspended during a dredging operation--fine-grained, clay-sized, and organic particles--are the ones that show the greatest affinity for chemical contaminants of various types. Dredging operations conducted in coarser sediments should experience little difficulty with resuspension or contamination.
- b. Different dredge types produce different amounts of suspended sediment in different parts of the water column. The cutter-head produces most of its resuspension near the bottom, as does the hopper dredge without overflow. The bucket dredge and hopper dredge with overflow produce suspended sediments throughout the water column. Sediments resuspended in the upper water column are of particular concern since a greater potential for suspended sediment dispersal exists in the upper water column.
- c. Sediment resuspension can be lessened by changing operating techniques or by modifying the equipment. Many researchers suggest that controlling cutter rotation speed, swing speed, and depth of cut of a cutterhead dredge can reduce sediment resuspension. In fact, any operating technique that improves the production of the cutterhead dredge will probably reduce resuspension. Hopper and bucket dredges will probably require some equipment modification to achieve a meaningful reduction in sediment resuspension.
- d. A wide variety of special-purpose dredges are available that appear to substantially reduce the potential for resuspension of sediment. However, most of these dredges have low production rates, and more research is needed to evaluate their areas of application and their limitations.

### Recommendations

39. Although additional research is being conducted to further quantify the effects of the equipment and operational modifications discussed in this paper, it is recommended that:

- a. A cutterhead dredge be considered whenever possible to limit resuspension. If properly operated, the cutterhead appears to produce the least resuspension of conventional equipment.

- b. When it is necessary to use a bucket dredge, it should be enclosed to reduce resuspension.
- c. Hopper dredges in general should not be used when sediment resuspension is a concern. If a hopper must be used, it should not be allowed to pump past overflow.

40. It is further recommended that, in addition to further field tests of conventional dredges, the testing of special-purpose dredge elements be conducted. This testing may require the purchase or construction of a special-purpose dredge for evaluation purposes.

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